TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE

12 FEBRUARY 1963

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

20060608046

NOLTR 63-18

TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE

By

Donna Price, J. F. Wehner and G. E. Roberson

ABSTRACT: No effect of free volume (ca. $10^{-3}cm^3$) introduced near the ignition wire could be detected in the experimental pressure-time curves for confined burning of an explosive. Rupture of the DDT tubes in the region of confined burning, for shots exhibiting transition to detonation, occurs more than 100 μsec after a pressure of 1 kbar is first attained; the plastic deformation of the tube requires more than 45 μsec. The long duration of the confinement and the pressure rises observed indicate that initiating pressures for DINA and pentolite are reached in the burning area near the igniter. A 1/4 in. thick Lucite filter in the path of the subsonic ionization front, downstream from the burning area, has no detectable effect on the propagation of the front. This disturbance is therefore pressure initiated and propagated; it is not a flame front.

PUBLISHED APRIL 1963

APPROVED BY: Carl Boyars, Chief
Physical Chemistry Division
CHEMISTRY RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, SILVER SPRING, MARYLAND

This report covers progress on a continuing program for the investigation of the transition from deflagration to detonation in high explosives and propellants; it is supported by project FR-59, Transition from Deflagration to Detonation. The present work produced new information on the sequence of events in the transitional region between ignition and steady state detonation as well as additional information on the nature of a subsonic ionized front in the transitional region. The new information contributes to the understanding of the sensitivity behavior of explosive materials.

R. E. ODENING
Captain, USN
Commander

Albert Lightbody
ALBERT LIGHTBODY
By direction

TABLE OF CONTENTS

TABLES

FIGURES

TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE

This progress report covers further studies of the transition from burning to detonation (DDT) in cast pentolite. It utilizes the experimental design of Macek (1) and ionization probes (1), strain gages (2), and pressure collapse probes (2), instrumentation described in the earlier reports. Quite simply, the experiments are designed to introduce a very large hot spot* in the cast explosive by use of a heated nichrome wire. The heated region is under high back confinement provided by the tube's bolt closure and under high lateral confinement provided by thick tube walls. The tubes are seamless, cold-drawn steel; their dimensions and properties are given in an appendix.

The nichrome wire and hence the ignition area is located about 4.8 mm (3/16 in.) from the end of the closure bolt i.e., 3/16 in. inside the cast explosive. That a burning reaction is induced by heating from the wire is indicated by the radial plastic deformation of about 3 mm. and rupture of the tube very near the hot wire as well as by the increase in pressure with time measured by strain gages mounted on the outside of the tube about an inch beyond the position of the nichrome wire. Of course, such a reaction is also deduced from its downstream effects: pressure fronts detected by pressure collapse probes sensitive to about 0.8 kbar, ionization fronts detected by ionization probes, and detonation indicated by the velocities of these fronts or a witness plate at the end of the tube or both.

Work covered in this report had two objectives: the investigation of the effect of introducing free volume on the observed pressure-time rise caused by burning near the ignition area and of the effect of interrupting established pressure and ionization fronts by a Lucite filter which would transmit pressures but would terminate any disturbances dependent on heat conduction or convection. Although the first investigation produced negative results, it yielded pressure-time curves for pentolite (previous curves are for DINA only) and new detailed information on the time-history of transition events. All results are reported in detail below.

---

* This is not to be confused with hot spots assumed to occur as a result of impact; such areas are estimated to be 0.01 to 0.001 mm in diameter and would not be detectable.

Introducing Free Volume into Charge

Previous work by Măcek (3) on the development of detonation from thermal initiation under conditions of massive confinement has shown that a rapid rise of pressure at the face of a cast explosive charge is necessary for the development of a shock wave within the body of the charge. Such a shock wave may or may not eventually grow into a steadily propagating detonation. A finite rise time for pressure has been observed in this work. Thermal ignition necessarily involves a gradual pressure buildup because of losses of heat to the surroundings. However, a one-dimensional adiabatic model for ignition of confined charges described by Maček results in an instantaneous pressure step in the absence of a free volume near the point of ignition. The finite rise time may be ascribed then to an effective free volume which is caused by thermal losses, the compressibility of the charge and its confinement, or by minute cavities which cannot be avoided in the casting process. Although cast charges are prepared carefully to avoid the introduction of cavities, it is nearly impossible to be certain that such cavities are absent.

In the theoretical development, the pressure-time profile of a burning confined charge is given approximately by the expression $p = p_o e^{kt}$, where k is inversely proportional to the free volume/unit area of the charge. From a fit of an experimental curve, an effective free volume of about $10^{-3} cm^3$ was estimated for the cast charges used. The model employed in this estimation is based on the assumption that a plane deflagration was proceeding through the charge and that the free volume was uniformly distributed at the surface where deflagration originated (See Appendix A).

To test the possibility that rise time is dependent on free volumes of this magnitude, known free volumes can be introduced into the charges and measurements made of the rise time. The constant k in the previously mentioned equation should be a linear function of the reciprocal of the known free volume. This test will be successful only if the variation in rise time due to the known free volume is greater than the variation caused by the lack of reproducibility of the charges.

Some shots have been fired in which a cavity near the ignition wire was introduced into pentolite charges by withdrawal of a fine wire which had been cast into the explosive. The wire was held in position during the casting process by small holes drilled through the casing of the charge; the holes were plugged after removal of the wire. The instrumentation used in these shots is described in references 2 and 3. The results showed no correlation of rise time or the tendency to detonate with the hole size (Fig. 1). Duplication of shots was not achieved. Indeed, the results suggest that the free volumes purposely introduced must be comparable to those introduced at random by the casting process, for the pressure-time curves are indistinguishable from those of earlier work where no free volume was deliberately introduced.

The steel tubes used for these preliminary shots were the first of a new lot of tubing because the earlier supply had been exhausted. The new tubing was ordered to duplicate the original (See Appendix B). In view of the unpromising preliminary results, it was thought that the new tubing might introduce enough differences to invalidate use of the old pressure calibrations and that such uncertainties could be elimated by a calibration of the new tubes. Accordingly the strain-gage circuitry, to record pressure-time in the burning area, was redesigned, and the new tubes fitted with strain-gages were calibrated. The new circuitry consisted of a power supply, a bridge circuit with trimmer resistances to compensate for drifting and a calibration circuit. The new calibration showed an output linear with pressure up to 3 kbar (4), as did the original calibration (2); the new calibration constant is 9.03 mv/kbar. The new tubes are **identical to the old in their response to slow loading.**

With the redesigned recording circuit, eight shots of supposedly identical charges were fired to develop a frame of reference. The pressure-time curves obtained for this set are shown in Figures 2 and 3. The charges of Fig. 2 were especially handled during the casting process to reduce cavities to a minimum. The reproducibility of these shots is poor; they do not follow a curve of the exact form $p = p_o e^{kt}$ except for limited regions at the ends of the curves. The tendency of the curves to be parallel at the upper ends suggests that the inertia of the walls is taking over at this point and that one is not observing a property of the explosive, but of its confinement. In other words, the pressure is increasing more rapidly than the walls can move in response to that pressure. The upper parts of the curve on Fig. 3 and three of the curves on Fig. 2 could be made to coincide closely if the time scale is shifted for each curve. This manipulation of the data is justified if the triggering level of the oscilloscope drifts so that each curve is triggered at a different pressure level. Since our triggering level could easily shift enough to explain the scatter in the initial points of the curves, the above manipulation is justified and we have therefore some reproducible curves among those of Figs. 2 and 3. However, this reproducibility occurs

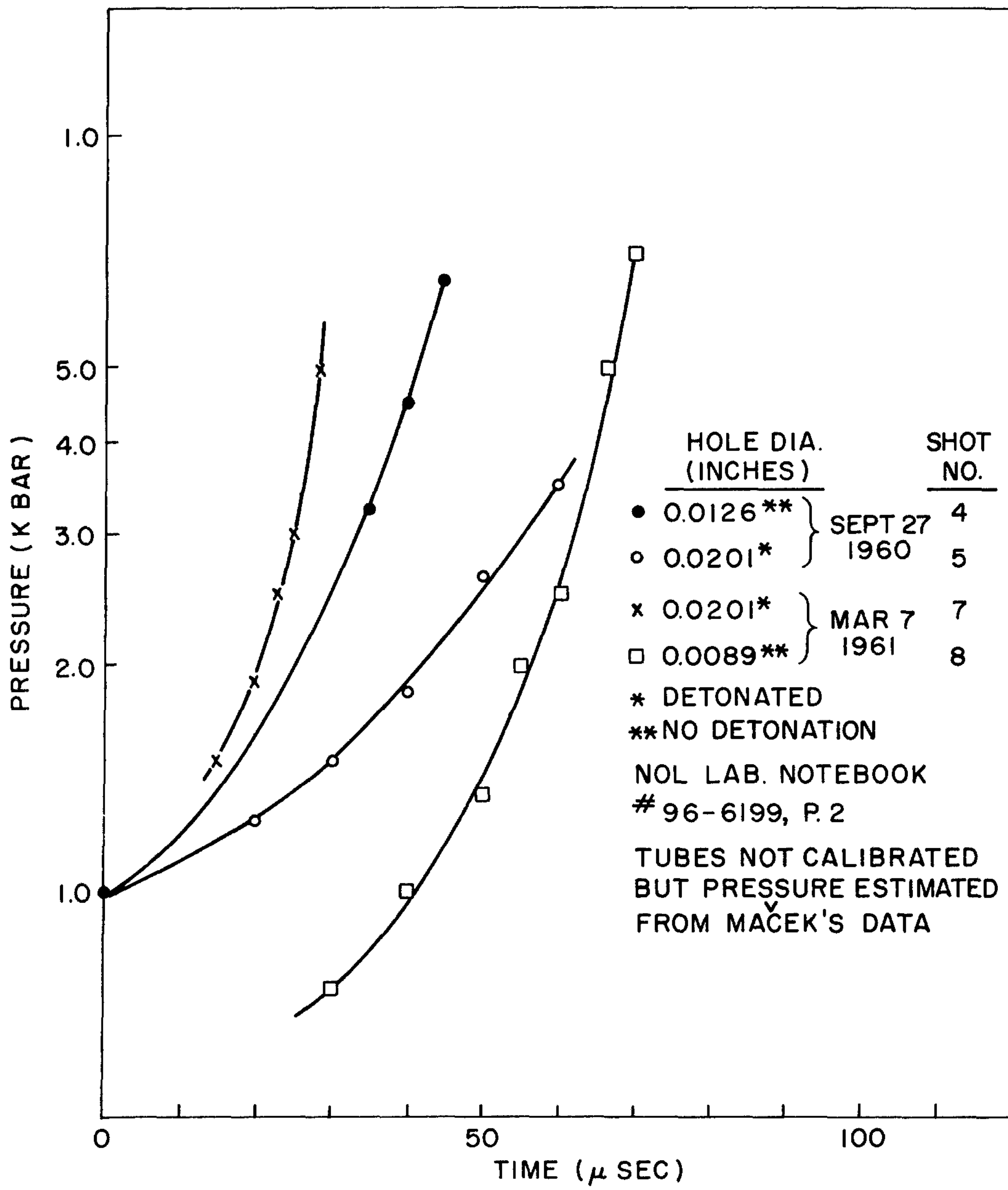


FIG. 1 PRESSURE-TIME CURVES FOR FREE VOLUME SHOTS

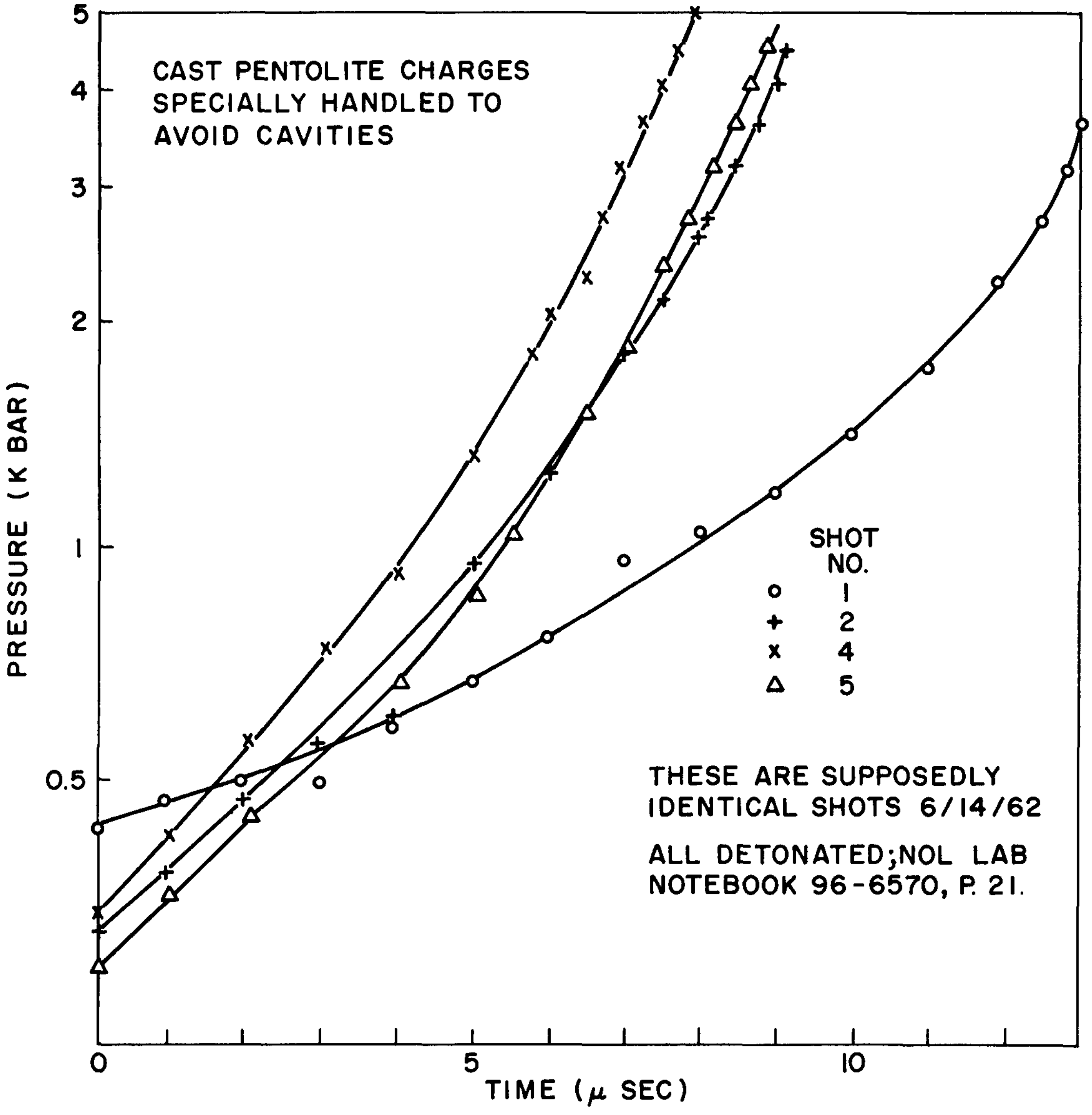


FIG. 2 PRESSURE TIME CURVES

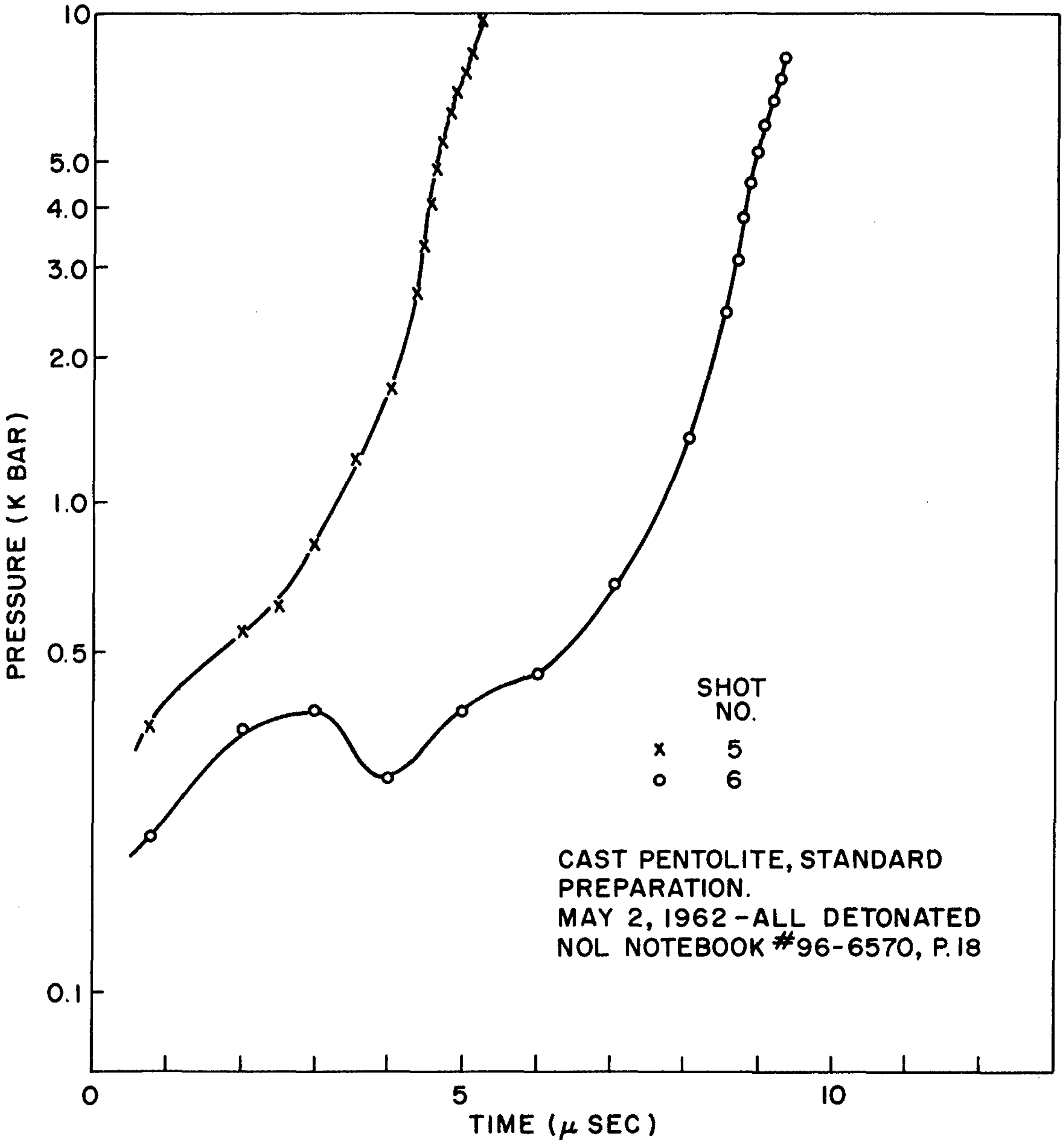


FIG. 3 PRESSURE - TIME CURVES

only for shots prepared at the same time and in any group of shots prepared together, not all shots can be so compared.

The rate of change dp/dt is smaller for charges of Fig. 2 than those of Fig. 3. However, the rates in both Figs. 2 and 3 are appreciably larger than those obtained with the previous instrumentation (Fig. 1). This is hard to explain since two sets of cold-drawn tubes showing the same static behavior would be expected to behave in a similar manner under dynamic loading. One possible explanation is incorrect machining of the tubes used in the runs of Figs. 2 and 3. It was found by examining fragments from the last 10 charges fired (group III of Table 1) that the tubes had been threaded for 57.2 mm (2.25 in.) of their length instead of the 36.6 mm (1.44 in.) requested. Thus the threading extended into the region around the hot wire with a corresponding weakening of the confinement there. If a similar error occurred earlier, data of the trends of Figs. 2 and 3 might be expected from greater strain and more rapid response than the regular tubes show to the same dynamic loading. Until this possibility can be checked, Fig. 1 which corresponds very closely to the previous work (2) will be used to describe the confined burning of pentolite.

The rate of change dp/dt at 5 kbar for pentolite (Fig. 1) is essentially the same as that found for DINA (2). As was suggested above, this may result from measuring the property of the confinement in both cases. Also as was pointed out in previous work, the pressures shown result from using a static calibration to interpret a dynamic loading; they are therefore indicative but not necessarily accurate.

The values of $\frac{dp}{dt}$ of this work, which may be taken from Figs. 1, 2 and 3, range from 0.01 to 2 kbar/µsec. The lowest value is 100 to 1000 times greater than the maximum observed in closed bomb burnings as reported by Wachtell, McKnight and Shulman (5). Rapid rates such as have been observed in the present work are necessary in order that mechanical shock waves can form in small charges. Wachtell et al report that enhanced burning, which they attributed to surface breakup, occurred in their work.

Jacobs and Buck (6) in earlier work on high pressure burning of explosives also noticed an enhanced burning; it was observed in the burning of plates of cast TNT and also, to some extent, in Fivonite. They attributed this rapid burning to cavities formed in the cooling process which might cause the burning to proceed in a manner other than normal to the geometrical outer surface of the charges.

In neither case, where enhanced burning was observed, did detonation occur prior to burn out. Detonation would not be expected as a result of enhanced burning at the pressure rates reported; it might occur if particle break-up continued, with pressure increase, until rates comparable to those observed in the confined burning of the present work were obtained. If, on the other hand, break-up stops, the rate of pressure build-up will fall back and a burning rate curve parallel to a normal curve will be observed. The curves of Wachtell et al show this tendency.

The poor reproducibility and unusual results in the present work (charge 5 in Fig. 1 and charge 1 in Fig. 2) are sufficient to show that variability in charge preparation and instrumentation can completely mask any free volume effects, in the range of free volumes used, for a single shot. Since the topic does not seem to justify a statistical study, work on it has been suspended until such time as more reliable charge preparation and instrumentation might be available.

Time-History of Transition Phenomena

In Ref. 7 it was reported that DDT experiments instrumented with both strain gages and ionization probes sometimes produced pressure-time records (strain gages) on which discharges of the ionization probes were superposed. It was suggested that this might provide a common time reference for the two records: pressure-time in the vicinity of the nichrome heating wire and position-time of the ionization front as it moved down the charge. Some success has been obtained with this approach. The instrumentation and geometry is as shown at the bottom of Fig. 4. The discharge of ionization probe 1, which triggered the sweep for the probe record, was clearly defined on the pressure-time record of shot 96-6199-2-4 (Fig. 1) thus presenting a common time point for the two records. In addition, the failure of the strain-gage, presumably caused by the expansion of the confining walls, initiated an obvious drift in the ground line of the probe record. As a result of these two interactions, it is possible to draw up a schedule of events for this shot as follows:

Shot 96-6199-2-4 (no detonation)

Schedule of Events

Time µsec	(Location, Distance from Nichrome wire) mm	Event
0	20.6 (14.3 - 27.0)	Pressure from reaction of explosive near hot wire reaches one kbar and triggers sweep for strain gage record. (This occurs 1 to 10 sec. after wire is heated.)
13.8	33.3	Discharge of ionization probe 1 (Event common to two records); this triggers sweep for probe record.
47.6	20.6	Pressure record reaches 5 kbar and goes off scale.
50.8	20.6	Strain gage fails - plastic yield of wall starts.
73.2	109.5	Discharge of probe 2; average velocity over interval 1.3 mm/µsec.
109.0	185.7	Discharge of probe 3; average velocity over interval 2.1 mm/µsec.
142.0	261.9	Discharge of probe 4; average velocity over interval 2.3 mm/µsec.

Although no other shots exhibited the common event of probe discharge, three others showed the failure of the strain-gage on the probe record. Since the separation of the two later events, strain gage record going off scale and strain gage failure, is only about 3 µsec and, therefore, of the same order of magnitude as the estimated error in time synchronization (1.2 µsec) it is sufficient for the present treatment to consider these events as simultaneous. Even if the separation were considered real, no better estimate can be made of the internal pressure than 5 kbar at the time plastic yield starts at the outer wall because the strain gage response during calibration is non-linear above 3 kbar and because only a static calibration is used.

Of the three ionization probe records showing the strain-gage failure, two were from charges in which detonation was achieved, but one of these (96-6199-2-5) showed an atypical pressure-time record (see Fig. 1). Consequently, data from the second charge 96-6199-2-1, for which no pressure record was obtained, was used to obtain the following schedule:

Time (μsec):	0	54.8	68	104	114
Event :	Probe 1	Strain gage failure	Probe 2	Probe 3	Probe 4

The velocities over the intervals are respectively 1.1, 2.1, and 7.6 mm/μsec. Combination of these data with those of 96-6199-2-4 results in the composite schedule of Fig. 4.

Fig. 4 is meant to be representative of the sequence of events occurring in shots for which the transition from burning to steady state detonation has been achieved; it is not an exact schedule for any specific shot. In addition to the information already developed, Fig. 4 contains the following items: the confining walls at the location of the burning area (8 mm beyond the Nichrome wire) have bulged to the extent of increasing the O.D. by 2 mm about 100 μsec after discharge of the first probe (see next section); the low velocity ionization front is preceded by a pressure front of 0.8 kbar or greater amplitude about 20-30 μsec earlier (Ref. 8 and Table 1) and by a pressure front of 2 kbar or greater amplitude about 5 μsec earlier (8); the pressure fronts move at about the same velocity as the ionization front in the subsonic region (8). There is some evidence (8) that the "2 kbar" pressure front exhibits a gradually accelerating velocity so that it merges with the steady state ionization front which is discontinuous with the subsonic ionization front; quite possibly the true 2 kbar front is overtaken by a higher amplitude, higher velocity pressure front.

It is of interest that the separation of the 0.8 kbar and 2 kbar fronts, about 15-25 μsec, is the same order of magnitude as the time required for the pressure at the burning area to increase from 0.8 to 2 kbar (Ref. 2 and Fig. 1). This fact supports the view that the pressure fronts are the result of the

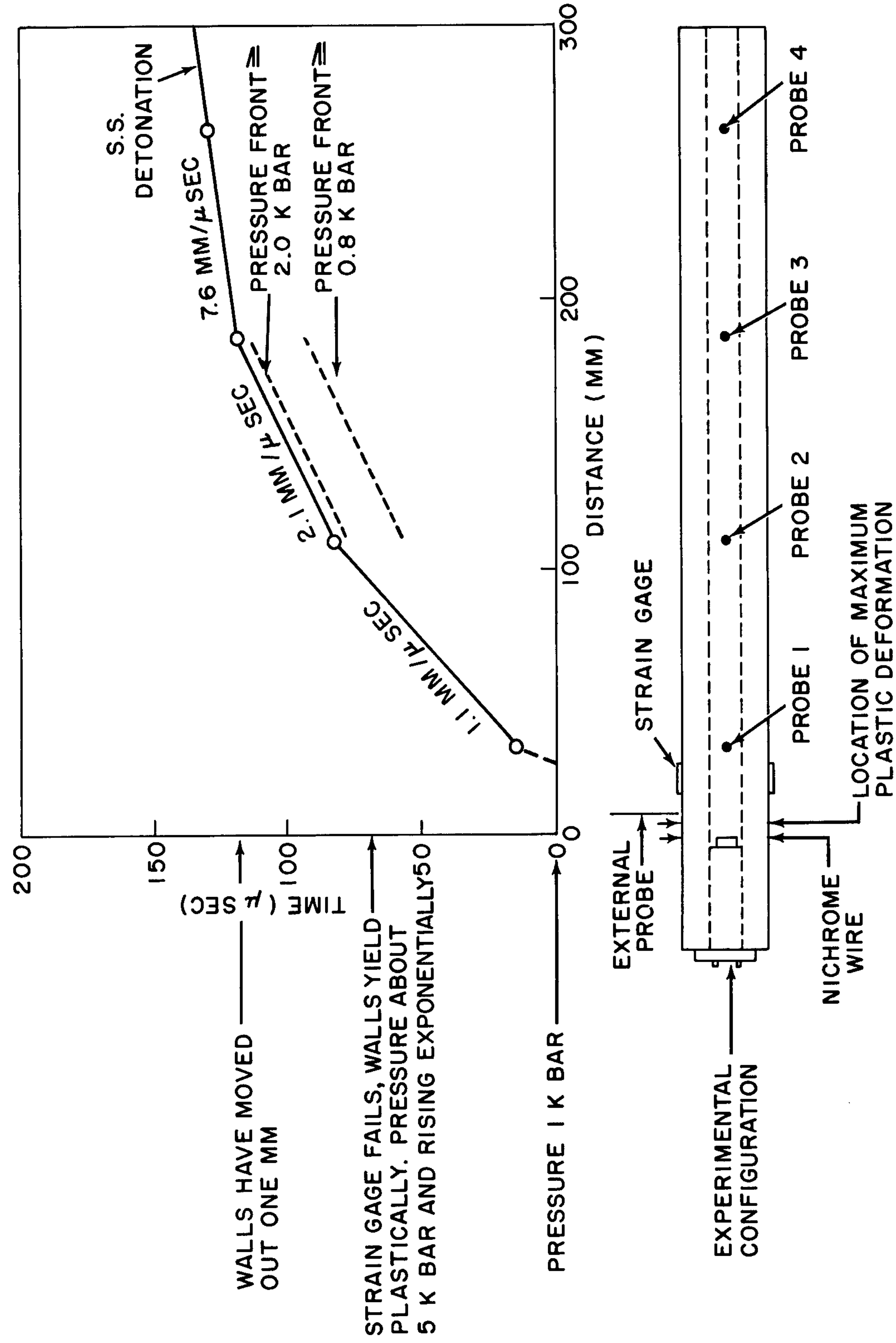


FIG. 4 TYPICAL SEQUENCE OF EVENTS IN TRANSITION FROM BURNING TO DETONATION

continuous gas loading in the burning area; they are detected as 0.8 kbar and 2 kbar fronts only because the collapse probes respond at those levels. A continuously recording pressure gage would probably duplicate downstream an attenuated pressure-time profile of the burning area. Of course, it is impossible to detect the point at which the amplitude of the pressure front exceeds the response pressure of the probes.

Another aspect of the pressure-time loading of Fig. 1, is that it is preceded by an unrecorded, long duration, low (if increasing) amplitude pulse within pressure ranges typical of the drop-weight impact test. Just as in the impact test, such a loading would be expected to create hot-spots. Such hot spots would not be detectable by any of the present instrumentation, but they would be expected to undergo confined burning and, if this occurred rapidly enough, it would reinforce the pressure fronts downstream from the original hot spot area. Since the time delay to reach 1 kbar at the nichrome wire is 1 to 10 sec., it is not likely that such reinforcement can occur within the present system but it might be a factor to consider in much larger systems.

Two cast explosives, DINA and pentolite, have shown successful transition to steady state detonation in the DDT configuration, and two others, Comp B and TNT, have failed to attain such a transition; for the first pair, the pre-detonation events must have resulted in a shock of amplitude equal to or greater than the initiating pressures for these materials in the DDT geometry. Approximate initiating pressures are 19 and 36 kbar respectively for pentolite and Comp B (9). (These were measured in steel tubes 0.5 in. I.D. and 1.5 in. O.D., a confinement slightly greater than that of the present work; this would tend to give a slightly lower critical pressure. Moreover, these charges were cast around continuous wires, a second factor which might contribute to a lower initiating pressure.) These approximate values are 1.61 and 1.69 times the initiating pressures measured in the standardized gap test geometry; hence an estimate for DINA and TNT can be made by multiplying the gap test values by 1.65. This gives approximate initiating pressures of 10.7 and 61.5 kbar respectively for DINA and TNT in the DDT geometry.

Initiating pressures are functions not only of the acceptor geometry, but also of the donor properties. On the assumption of similarity in the pressure loading from tetryl donors (standardized gap test donor) and the pressure loading generated by the burning explosive in the DDT test*, successful transition for DINA and pentolite means that shock pressures of about 11

* This assumption is being examined theoretically (10)

and 19 kbar respectively were attained. Since the strain gage records indicate an internal pressure of 5 kbar, increasing exponentially with time, at the beginning of plastic deformation of the DDT tube and since rupture of the tube does not occur until about 50 μsec later (Fig. 4), it seems highly probable that pressures as high as 19 kbar can be attained, although not maintained, in the reacting area. Petrone (10) has recently found in a 1-D theoretical treatment, that an exponential pressure rise up to the initiating pressure on the explosive boundary is sufficient to induce transition to detonation downstream from the boundary. It seems probable that transition will occur if the initiating pressure can be reached in the burning area and not otherwise. This would explain successful transition in the DDT configuration for two relatively shock sensitive explosives DINA and pentolite as well as the failure to obtain transition for the less sensitive cast Comp B and TNT (initiating pressures of about 36 and 62 kbar, respectively). For TNT, the maximum measured pressure in the burning area was only about 3 kbar (7), and the DDT tubing was not plastically deformed.

Finally, from Fig. 4, steady state detonation has been established at 185 mm from the hot wire and possibly earlier. Therefore, it was probably established before the high pressure in the burning area had been completely relieved by bursting of the tube. The average velocity of 2.1 mm/μsec between probes 2 and 3 is probably near the constant velocity observed in many previous runs and probably holds for much of the interval between probes 1 and 2; there it is masked by the slow buildup time in the first part of the interval. It is interesting that this velocity is about that to be expected for a plastic wave when the static value of the bulk modulus of the explosive is used.*

*Assume elastic velocity of 2.7 mm/μsec, that of Comp B (11), a loading density ρ_o of 1.7 g/cc, and Poisson's ratio ν of 0.3 (12). Then from

$$c = 2.7 = \sqrt{\frac{3k}{\rho_o} \quad \frac{1-\nu}{1+\nu}}$$

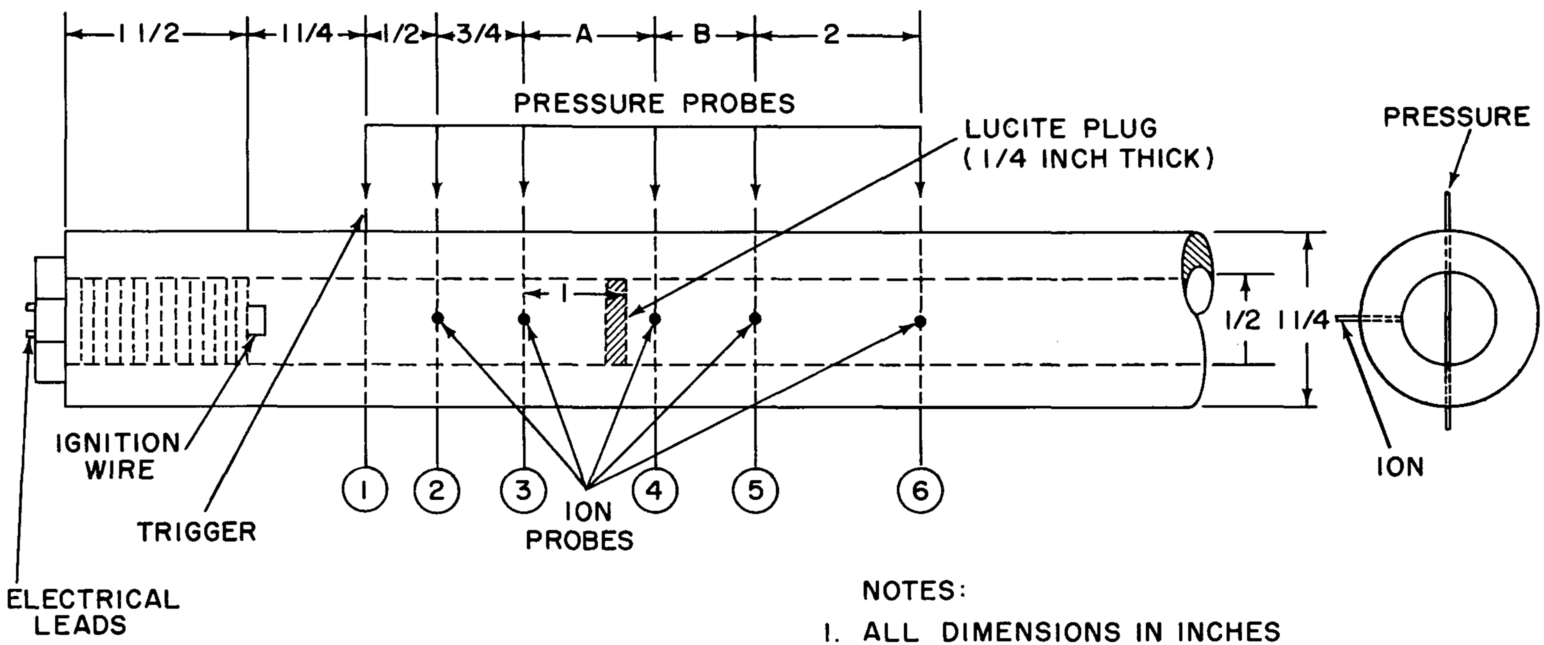
the bulk modulus k = 76.8 kbar. Measured values for cast explosives are 48 to 90 kbar (12). The expected velocity for the plastic wave would then be approximately $\sqrt{k/\rho_o}$ or 2.2 mm/μsec.

Low-Velocity Ionization Front

Additional information which came from the earlier work on confined charges was the demonstration of a quasi-stable low velocity (1-2 mm/μsec) ionization front following the pressure front, initially at approximately the same subsonic velocity (13). The onset of detonation occurs rapidly but continuously from the pressure front after it has traveled as much as 10 cm; the corresponding change in velocity of the ionization front is discontinuous and probably involves changing from one disturbance to another.

In order to characterize the trailing, low-velocity low-pressure ionization front, an inert barrier was used; this would stop a flame front while allowing the pressure front to propagate without appreciable degradation if the impedance of the barrier is near that of the explosive. Flames, which propagate by virtue of the transport of heat and/or reaction products into a region ahead of the burned gas zone, could not traverse such a barrier. Lucite was used as a barrier material in charges prepared and instrumented as shown in Fig. 5. The pressure probes detect a compression front of 0.8 kbar or more while the ion probes discharge in an ionization front of a resistance of 100 ohms or less. The records obtained from this work consist of pips on an oscilloscope trace which is triggered by the initial pressure probe placed about one inch from the hot wire. Details of instrumentation are given in Refs. 1 and 2.

Although the first probe, a pressure collapse probe, was used to trigger both oscilloscopes, separate records were obtained for (a) the set of six pressure probes and (b) the set of five ionization probes. Within each set, however, there was no distinction between probes such as a change of amplitude on adjacent probes. Consequently, for shots in which some probes of the set failed to function, the usual situation, the record pips had to be assigned to specific probes. For this purpose, as well as for scanning the variations from shot-to-shot, a space-time display of the data proved most helpful. The assignments are given in Table 1 and displayed in Figs. 6 through 9. Well within the experimental errors (positioning of thick probes, variation in synchronization of two scopes, reading of records), the pressure probe curves indicate a long path at a constant subsonic velocity; the velocity is unaffected by passage through the Lucite. Some attenuation of the pressure front by the inert filter and consequent decrease in wave velocity would be



SERIES	A	B
I	1.0	2.0
II	2.0	1.0
III	1.5	2.0

NOTES:

1. ALL DIMENSIONS IN INCHES
2. TUBE FILLED WITH CAST PENTOLITE. TOTAL LENGTH 13 1/2 INCHES. CHARGE LENGTH 12 INCHES.

FIG. 5 EXPERIMENTAL ARRANGEMENT FOR LUCITE PLUG SHOTS

TABLE 1

Arrival Time at Probes (μsec)

Run	Probe Record[a]	Initiating Probe	Probes 2	Probes 3	Lucite	Probes 4	Probes 5	Probes 6	Comment
I-		0	12.7	31.8	50.8-57.2	57.3	108.0	158.8	Spacing, mm
1	P	0	12.1	19.2		F[b]	61.3	81.2	
1	I	-	31.7	44.5[c]		F	71.0	85.9	
II-		0	12.7	31.8	50.8-57.2	82.9	108.0	158.8	Spacing, mm
1	P	0	4.3	16.3		F	51.3	62.1	
1	I	-	25.7	48.3[c]		57.9	70.6	88.1	
2	P	0	11.3	F		44.9	56.7	76.6	
2	I	-	17.8	25.2		50.2	61.0	78.8	
4	P	0	9.7	21.1		56.1	61.2	F	
4	I	-	F	F		61.9	70.5	81.9	
III-[d]		0	12.7	31.8	50.8-57.2	69.9	120.7	171.5	Spacing, mm
2	P	0	d	54.4		58.4	73.4	83.8	
2	I	-	Only one probe discharged at 45.5						
3	P	0	13	25.1		46.5	57.0	d	Electrical connection between two sets of probes
3	I	-	Identical with pressure probe record						
4	P	0	0.5[c]	F		36.2	77.4[e]	101.9	
4	I	-	5.4	F		47.2	62.2	F	

Table 1 (Cont'd)

Arrival Time at Probes (μsec)

Run	Probe Record[a]	Initiating Probe	Probes 2	Probes 3	Lucite	Probes 4	Probes 5	Probes 6	Comment
III-[d]									
5	P	0	14.0	20.5		84.1[c]	74.9	d	
5	I	-	34.0	F		F	F	F	
6	P	0	3.5	F		42.3	77.8	F	
6	I	-	No record - bad film						
7	P	0	7.1	13.9		F	67.2	F	
7	I	-	11.2	F		53.5	78.9	92.9	
8	P						18.8	51.7	Triggered too late by external probe
8	I	-					13	37.0	
9	P	0	F	20.5		F	74.0	106.5	
9	I	-	54.5	56.3[c]		89.1	112.1	126.9	
10	P	0	12.5	32.5		69.7	130.0	152.0	
10	I	-	96.0	122.2[c]		127.0	148.8	158.0	

a. P indicates pressure probe record; I, ionization probe record.
b. F indicates failure of probe.
c. Arrival times and corresponding distance intervals not used in computation of velocities in Table 2.
d. Probe was found shorted or had been removed before shot was made.
e. Probe originally shorted had been repaired before shot was made.

Nichrome wire 42.9 mm from tube end; first (trigger) probe was a pressure probe placed at 69.9 mm from tube end. See Figure 4 and Appendix B.

Series I : Notebook 96-6199, p. 17
Series II : Ibid., p. 15
Series III: Notebook 96-6570, p. 24

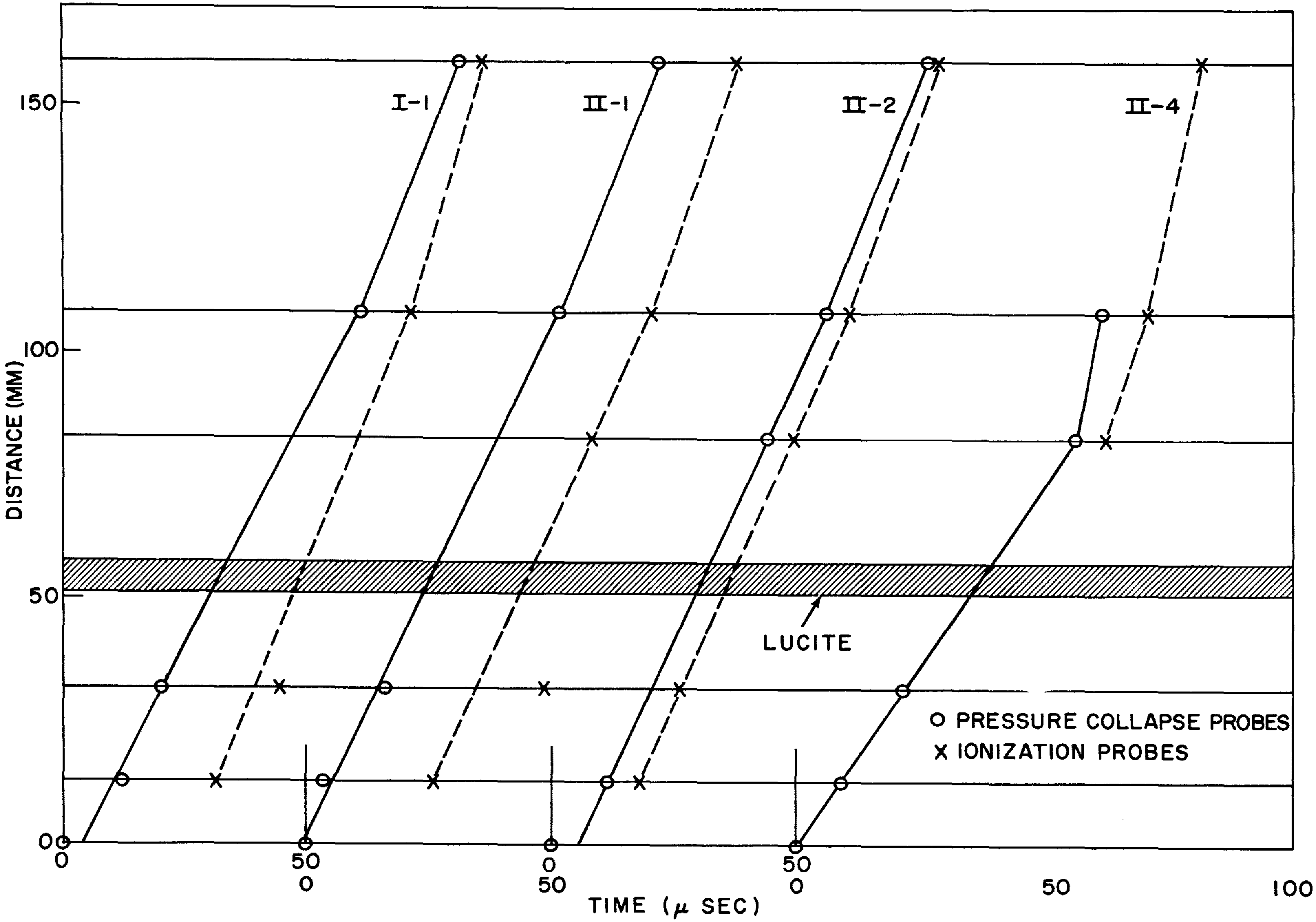


FIG. 6 PROBE POSITION VS RESPONSE TIME FOR SERIES I AND II

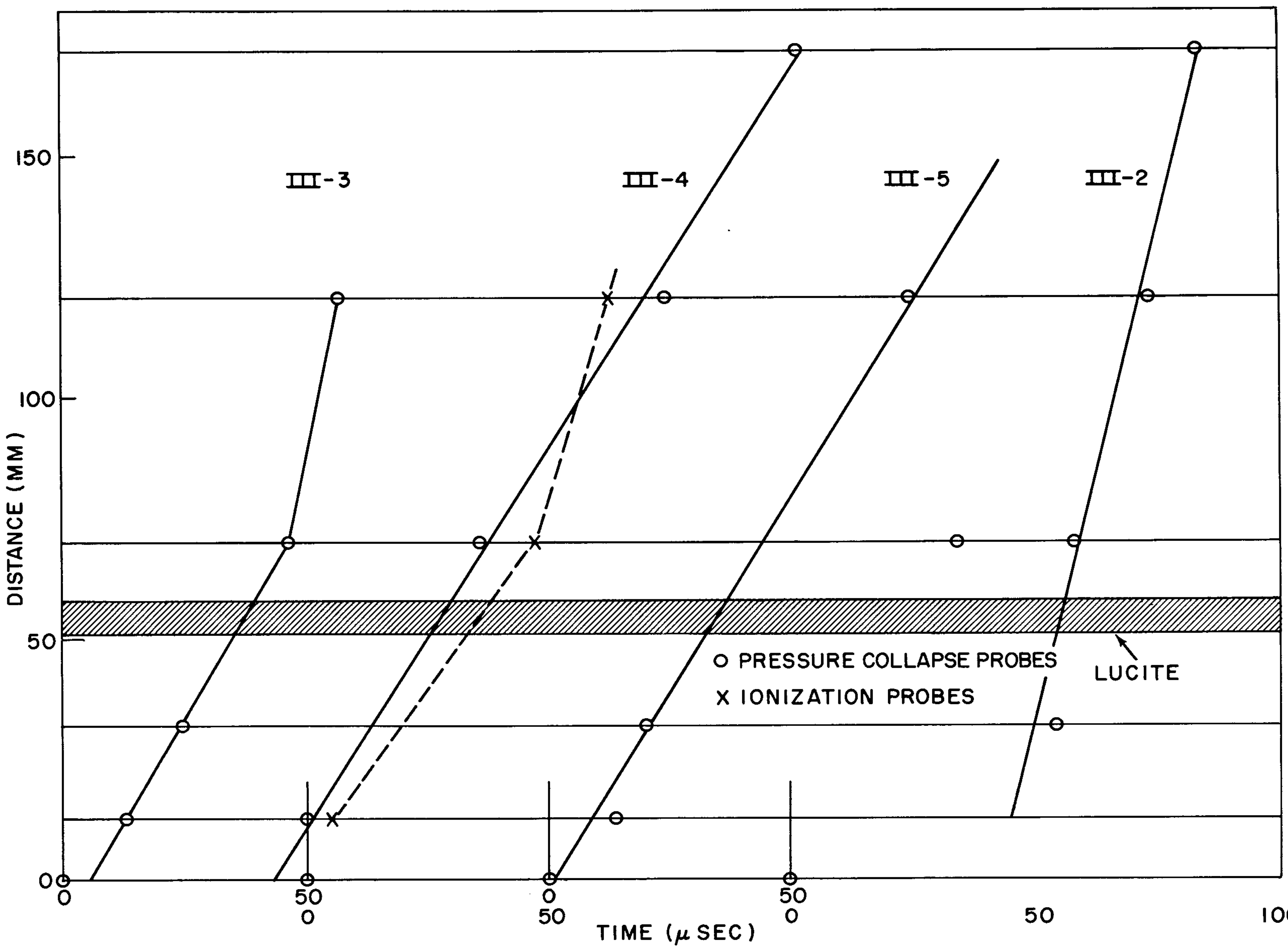


FIG. 7 PROBE POSITION VS RESPONSE TIME FOR SERIES III-2 TO 5

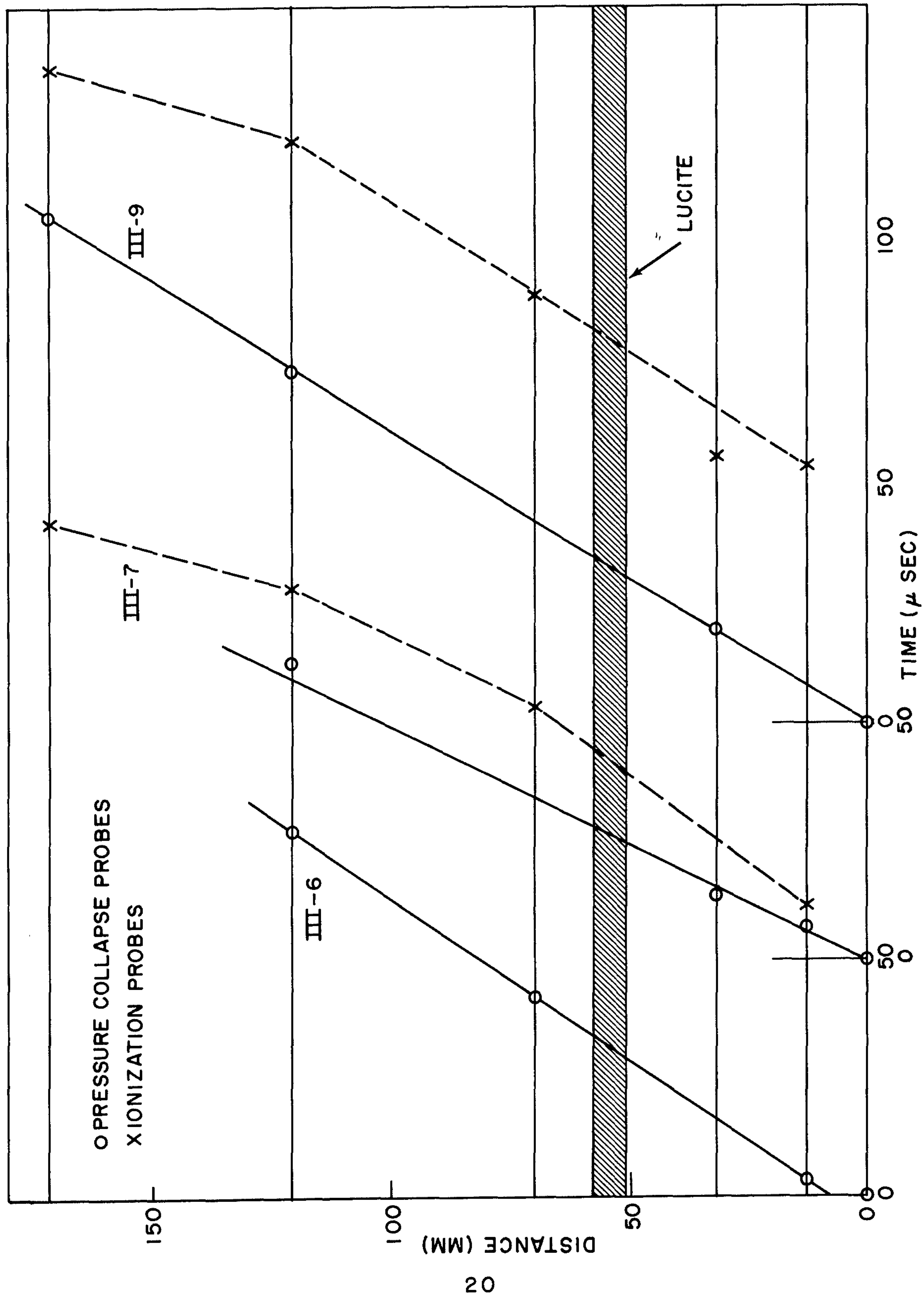


FIG. 8 PROBE POSITION VS RESPONSE TIME FOR SERIES III 6,7, AND 9

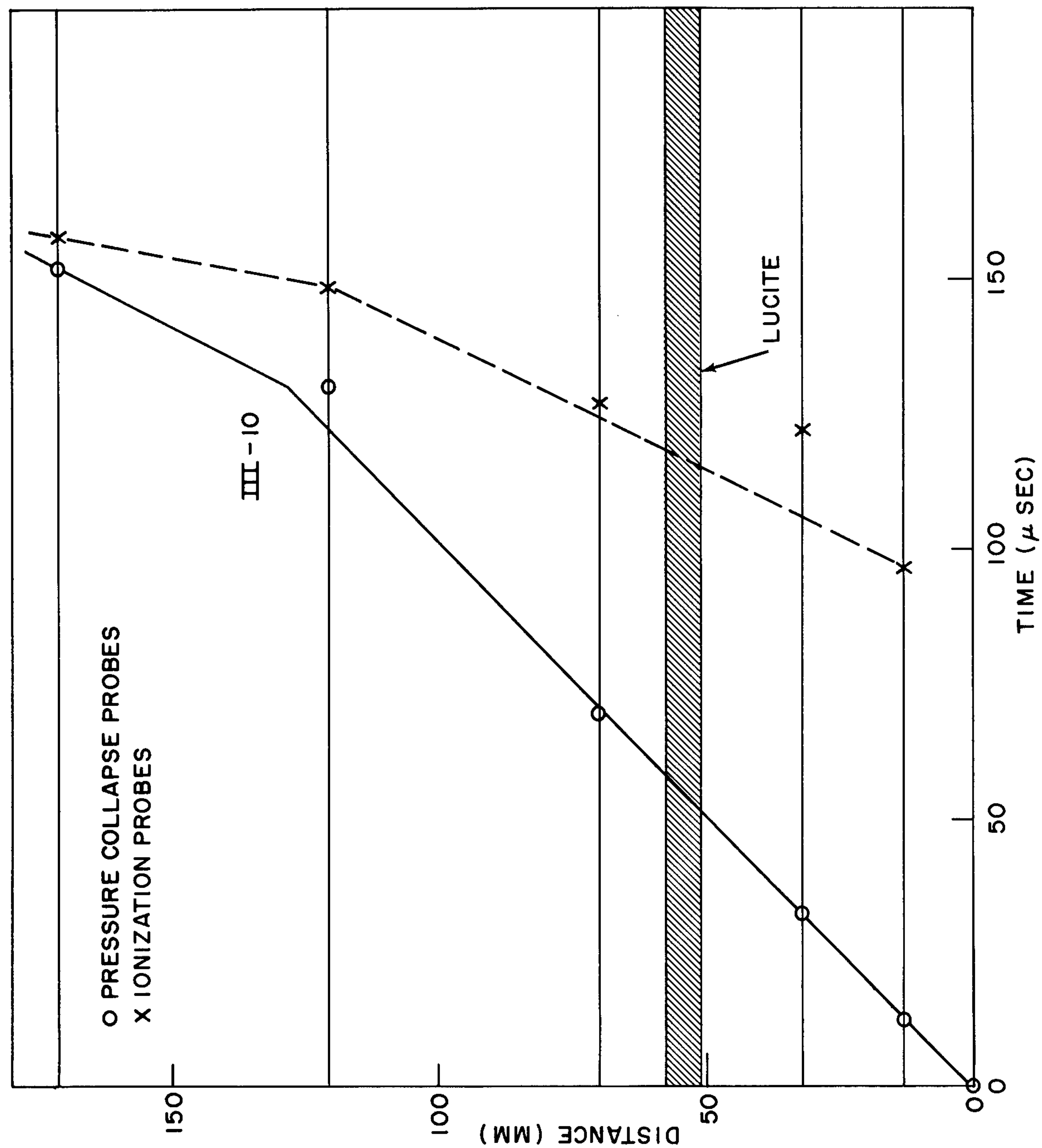


FIG. 9 PROBE POSITION VS RESPONSE TIME FOR SHOT III-10

expected. Failure to observe such an effect* might result from the long duration of the pressure loading from the burning area as contrasted to the short duration of an explosive loading where attenuation is observed. It might, of course, be only the apparent result from erroneous identification of pips in some shots, but enough nearly complete runs are present to support the present assignment.

In these runs the ionization probes proved less reliable than the pressure probes. Ionization front data are also displayed in Figs. 6 through 9 and confirm the earlier work in showing the ionization front following the pressure front at approximately the same velocity. The ionization front, like the pressure front, shows no detectable effect of the Lucite filter on its velocity. Note that the second ionization probe response has been ignored in drawing four of the curves. In one case, that of shot III-9 there is no explanation of the position of this response, but in the other three the probe location is such that the rarefaction reflected from the Lucite surface could reach the probe and partially quench the reaction producing ions before the probe responded. In such a case probe response would be delayed by the amount of time the reaction required to build up again the necessary charge concentration. This interpretation is strengthened by run II-2 in which the velocity of the ionization front is sufficiently high to discharge the second ionization probe before the rarefaction could reach it. It might be added that if the three points described were not ignored in drawing the curves, the curves would indicate that the presence of the Lucite filter caused an <u>increase</u> in the velocity of the ionization front, a phenomenon for which there is no reasonable explanation.

It is customary to study build-up processes by considering the velocity of the disturbance over successive increments of the path it travels. It should be kept in mind, however, that taking the derivative (in this case, using the ratio of two differences) greatly magnifies the error and does not generally produce smooth trends. This is illustrated by the velocity data of Table 2 which also contains the slopes read from the constant velocity section of Figs. 6 through 9; these latter are smoothed values, but useful in considering the subsonic regions.

---

* In the assignments made in Table 1, one third of the shots showed failure of pressure probe 4, that placed just beyond the Lucite filter. This might be due to a small attenuation of the pressure amplitude which is not reflected by the velocities within the present precision. The assignment in III-5 attributes shorting of pressure probe 4 to a later, higher pressure front after slight attenuation of the first pressure front.

TABLE 2

Velocities between Probes (mm/μsec)

<table>
<tr><th>Run</th><th>Probe:
Probe Record</th><th colspan="5">1 2 3 Lucite 4 5 6</th><th>Initial Constant Velocity From Curve</th><th>Initial Separation of Fronts[b] μsec</th></tr>
<tr><td>I- 1</td><td>P</td><td>1.1</td><td>2.7</td><td colspan="2">← 1.8 →</td><td>2.6</td><td>1.9</td><td>20.5</td></tr>
<tr><td>1</td><td>I</td><td>-</td><td colspan="3">← 2.4 →</td><td>3.4</td><td></td><td></td></tr>
<tr><td>II[a] 1</td><td>P</td><td>3.0</td><td>1.6</td><td colspan="2">← 2.1 →</td><td>2.4</td><td>2.0</td><td>20.5</td></tr>
<tr><td>1</td><td>I</td><td>-</td><td colspan="2">← 2.2 →</td><td>2.0</td><td>2.9</td><td></td><td></td></tr>
<tr><td>2</td><td>P</td><td>1.1</td><td colspan="2">← 2.1 →</td><td>2.2</td><td>2.6</td><td>2.1</td><td>6.5</td></tr>
<tr><td>2</td><td>I</td><td>-</td><td>2.6</td><td>2.0</td><td>2.4</td><td>2.9</td><td></td><td></td></tr>
<tr><td>4</td><td>P</td><td>1.3</td><td>0.9</td><td>1.5</td><td>5.0</td><td>-</td><td>1.5</td><td>—</td></tr>
<tr><td>4</td><td>I</td><td>-</td><td></td><td></td><td>3.0</td><td>4.5</td><td></td><td></td></tr>
<tr><td>III- 2</td><td>P</td><td colspan="2">← 0.6 →</td><td>(9.5)</td><td>3.4</td><td>4.9</td><td>4.1</td><td>—</td></tr>
<tr><td>3</td><td>P</td><td>1.0</td><td>1.6</td><td>2.4</td><td>2.4</td><td>-</td><td>1.7</td><td>—</td></tr>
<tr><td>4</td><td>P</td><td colspan="3">← 1.9 →</td><td>0.6</td><td>2.1</td><td>1.6</td><td>4(10)</td></tr>
<tr><td>4</td><td>I</td><td>-</td><td colspan="2">← 1.4 →</td><td>3.4</td><td>-</td><td></td><td></td></tr>
<tr><td>5</td><td>P</td><td>0.9</td><td>2.9</td><td colspan="2">← 1.6 →</td><td></td><td>1.6</td><td>20</td></tr>
<tr><td>6</td><td>P</td><td>3.6</td><td colspan="2">← 1.5 →</td><td>1.4</td><td></td><td>1.5</td><td>—</td></tr>
<tr><td>7</td><td>P</td><td>1.8</td><td>2.8</td><td colspan="2">← 1.7 →</td><td></td><td>2.0</td><td>4.1(20.0)</td></tr>
<tr><td>7</td><td>I</td><td>-</td><td colspan="2">← 1.4 →</td><td>2.0</td><td>3.6</td><td></td><td></td></tr>
<tr><td>8</td><td>P</td><td></td><td></td><td></td><td></td><td>3.6</td><td></td><td>—</td></tr>
<tr><td>8</td><td>I</td><td></td><td></td><td></td><td></td><td>4.6</td><td></td><td></td></tr>
<tr><td>9</td><td>P</td><td colspan="2">← 1.6 →</td><td colspan="2">← 1.7 →</td><td></td><td>1.6</td><td>—</td></tr>
<tr><td>9</td><td>I</td><td>-</td><td colspan="2">← 1.7 →</td><td>2.2</td><td>3.4</td><td></td><td></td></tr>
<tr><td>10</td><td>P</td><td>1.0</td><td>1.0</td><td>1.0</td><td>0.8</td><td>2.3</td><td>1.0</td><td>83.5(25)</td></tr>
<tr><td>10</td><td>I</td><td>-</td><td colspan="2">← 1.8 →</td><td>2.3</td><td>5.5</td><td></td><td></td></tr>
</table>

a. Shots of Series II did not punch hole in witness plate and would be rated A on scale of Ref. 11. All other shots did puncture plate and would be rated D on the same scale.

b. Values in parentheses give subsequent maximum on minimum separation within constant velocity range of pressure front. This is given only when different from initial value.

Of the twelve runs, ten exhibit initial velocities of 1.5 to 2.1 mm/μsec; one has a velocity as low as 1 mm/μsec; and one, III-2, as high as 4.1 mm/μsec. This last shot should be excluded as completely atypical. In it, there was an interval of 54 μsec between the response of the trigger probe and that of the second pressure probe; after that, an unusually high velocity pulse passed over the remaining probes. It is suggested that the trigger probe was collapsed by a low pressure (0.8 kbar), fading front or, possibly, immediately after the response of the trigger probe, the burning front, near the nichrome wire, broke into a large enough cavity in the charge to lower drastically the pressure (and hence temperature) of this region. As the reaction built up again, with a greater area of burning surface, it could eventually exhibit a much higher rate dp/dt than usually found and send out a high pressure, high velocity front. Such a later front could not be detected by the first pressure probe (already collapsed) but would register on the remaining probes to give the curve seen in Fig. 7.

The lowest velocity run, III-10, is not atypical because occasional velocities as low as 1 mm/μsec have been observed in the transitional region. This is the first very low velocity shot in this work, however, which contained both pressure and ion probes. The record is unusual in exhibiting an extremely long interval (84 μsec) between the pressure and ionization fronts. In this case, the amplitude of the pressure wave was low - possibly little more than the 0.8 kbar necessary to collapse the probes; this is indicated by its low velocity. The ionization front was probably established by a later, stronger pressure front, and, after being established, travelled at a velocity nearer that of its initiating disturbance and well above that of the first pressure front measured.

Also listed in Table 2 are the initial, and, in some cases, later separation between the pressure and ionization fronts in the constant velocity region of the former. The pressure front always leads, and the trend is larger separation with decreasing velocity (and hence amplitude) of the pressure front, a relationship to be expected for a pressure dependent phenomenon.

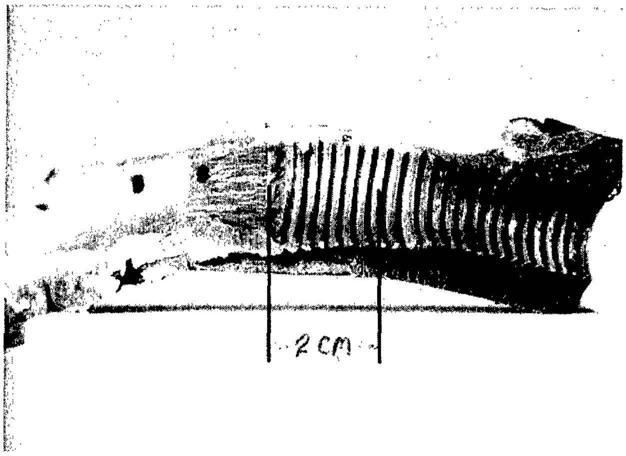
The velocities of the last interval (probes 5 to 6) indicate detonation for shots III-5, 10, and probably 2; but damage to the witness plate indicated detonation for all of group III and I-1, failure for group II. In a typical shot without the Lucite plug (Fig. 4) steady state detonation was achieved at (or before) 186 mm from the nichrome wire. Probes 5 and 6 are respectively 122.2 mm and 173.0 mm from the nichrome wire. It appears therefore, that the Lucite plug has not delayed the transition to detonation. (This is also indicated by Figs. 6 through 9.)

However, the location of the onset of detonation has varied so widely (6 to 18 cm (13)) that control charges prepared at the same time as the Lucite plug charges must be fired for a more valid comparison on this point.

It is quite evident from the data of Table 2 that probe measurements in the region of subsonic disturbances are inadequate to show whether transition to steady state detonation will occur within the DDT geometry. It is probable that other factors such as method of casting of the charge, rate of pressure buildup around the hot wire, and the duration of the confinement around the burning explosive are determinant. Difference in castings is believed to be responsible for the detonation of charges in Groups I and III and the failure to detonate of those of Group II. A greater effort to control the casting is being made, but there is as yet no quantitative method of assessing the differences in the charges produced. The variability of pressure buildup around the hot wire has already been described in a previous section; comparable variability in subsonic disturbances can be seen in Figs. 6 through 9. More simultaneous measurements in the two regions will be made.

A start has been made in studying the third factor of possible importance, the duration of confinement in the burning area. By studying fragments recovered after the shots, it was found that maximum plastic distortion of the tube is about 3 mm on the radius. The maximum distortion is located about 4.7 mm from the nichrome wire, but the entire distortion covers about 2.5 cm length along the tube (see Fig. 10). To obtain an idea of the time required to effect this distortion, an external probe was set up 1 mm from the tube wall at a longitudinal location of 7.9 mm from the nichrome wire. The external probe was used in shots III-9 and III-10; it was shorted out at 109.5 μsec and 92 μsec respectively after the response of the triggering probe. As shown in Fig. 4, this gives an estimate of about 45 μsec from the beginning of plastic deformation to a radial increase of 1 mm and of about 114 μsec from a pressure of 1 kbar in the burning region to a radial distortion of 1 mm.

Despite the incomplete data of Tables 1 and 2, a result of unpredictable difficulties in electronic instrumentation and charge preparation, eight of twelve records clearly demonstrate that the low velocity ionization front, interrupted by a short non-reactive filter, will re-establish itself beyond the filter. This has been established even if different assignments from those of Table 1 are made. Moreover, runs III-9 and III-10 show that it is re-established within 12.7 mm (0.5 in.) of the filter with apparently no effect on its propagation velocity.



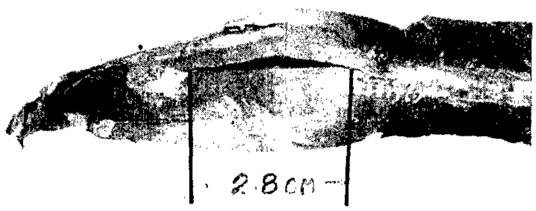


FIG. 10 FRAGMENTS OF TUBE SHOWING PRESSURE RUPTURE IN VICINITY OF HOT WIRE

The disturbance is, therefore, not dependent on transport properties and should not be referred to as a flame front. It is pressure initiated and propagated, and probably results, as Maček suggested, from a partial reaction critically dependent for its existence on the exact pressure level.

It is not clear how the ionization front observed here for dense charges is related to the luminous combustion front (0.8 mm/μsec) observed by Griffiths and Groocock (14) in porous charges. They may both be manifestations of the same phenomenon i.e., a critically pressure dependent reaction. However, proposed mechanisms of buildup to the necessary pressure differ in the two cases. For cast charges, the mechanism is a confined burning in which any convective propagation is minor; for porous charges, the suggested stages are slow conductive burning followed by fast convective burning (14). For cast charges the greatest combustion* pressure is manifest within a distance of one diameter from the igniter in contrast to the porous charges where the largest combustion pressure appears 5 to 20 diameters downstream from the igniter.

Information about the low velocity ionization front in cast explosives has been accumulated throughout the course of the DDT investigation. Its present status can be summarized as follows:

1. It is pressure initiated and propagated.
2. Its velocity of propagation is neither very reproducible nor strictly constant. Values between 1 and 2.5 mm/μsec have been observed (15).
3. The associated pressure, as indicated by tube damage is low (13).
4. It is not an ordinary deflagration; the ion probes which detect it will not respond to ordinary flame fronts. Its resistance of about 100 ohms is greater than that of a detonation front (<1 ohm) but lower than that of ordinary deflagration (13).
5. Because of properties 2 through 4, it is assumed to result from a partial reaction - possibly on the grain surface (15).
6. From a knowledge of steady state behavior in deflagration and detonation, the persistence of such a reaction must depend on initiation by a quite critical pressure amplitude (15).

---

* This is not a steady state but an accelerating reaction.

In the present work, as in the past, the low-velocity ionization front has been detected in every trial save those in which failure of instrumentation is suspected. Its appearance is no indication of whether transition to detonation occurs. It is believed to be an incidental phenomenon which occurs only because, in the course of continuous pressure buildup, the critical pressure for its initiation must be reached (as well as passed). Since there is no obvious way in which it can contribute to the transition, further study of it will be made only in conjunction with developing additional information on the transitional phenomena and factors affecting it.

REFERENCES

1. A. Maček and R. W. Gipson, "Sensitivity of Explosives V. Transition from Slow Burning to Detonation in Cast Pentolite", NAVORD Report 5758, 1 Nov 1957.

2. A. Maček, R. W. Gipson, and P. F. Donovan, "Sensitivity of Explosives VI. Transition from Slow Burning to Detonation: Pressure and Velocity Measurements", NAVORD Report 6104, 12 May 1958.

3. A. Maček, "Transition from Deflagration to Detonation in Cast Explosives", J. Chem. Phys. 31, 162-67 (1959).

4. NOL Laboratory Notebook 96-6570, pp. 31-33.

5. S. Wachtell, C. E. McKnight, L. Shulman, "Establishment of Improved Standards for Classification of Explosives and Propellants", Picatinny Arsenal Tech Rept. DB-TR:3-61, June 1961.

6. S. J. Jacobs and W. B. Buck, "Closed Bomb Burning of High Explosives and Propellants", Div. 8 Nat. Defense Res. Comm. OSRD Rept. 6329, p. 41 (1946).

7. R. W. Gipson and A. Maček, "Transition from Slow Burning to Detonation: Partial Report on Experimental Work in 1958-1959", NAVORD Report 6867, 17 Mar 1960.

8. R. W. Gipson and A. Maček, "Transition from Slow Burning to Detonation: Flame Fronts and Compression Waves During Growth of Detonation", NAVORD Report 6759, 23 Nov 1959.

9. D. Price and I. Jaffe, NOL, Unreported data.

10. Physical Chemistry Division Meeting, NOL, 8 Nov 1962.

11. S. J. Jacobs, T. P. Liddiard, and B. E. Drimmer, "The Shock-to-Detonation Transition in Solid Explosives", Preprints of Discussion on Detonations presented at IXth International Symposium on Combustion, Ithaca, N.Y., 27 Aug - 1 Sep 1962.

12. Mechanical Properties of Explosives 1958 Addendum to Sect. D3, Explosion Effects Data Sheets, NAVORD Report 2986, 14 Jun 1955.

13. R. W. Gipson and A. Maček, "Flame Fronts and Compression Waves During Transition from Deflagration to Detonation in Solids", Eighth Symposium (International) on Combustion, Williams and Wilkins, Baltimore (1962) pp 847 - 54.

REFERENCES (Cont'd)

14. N. Griffiths and J. M. Groocock, "The Burning to Detonation of Solid Explosives", J. Chem. Soc. (London) 4154-62 (1960).

15. A. Maček, "Sensitivity of Explosives", Chem. Revs. 62, 41-63 (1962).

16. A. Maček, "Transition from Slow Burning to Detonation: A Model for Shock Formation in a Deflagrating Solid", NAVORD Report 6105, 12 May 1958.

APPENDIX A

Estimate of Free Volume

From an exponential burning rate law and simple assumptions for the gas products, Maček (16) derives the expression,

$$t = \frac{V_o C}{A\beta} \int_{p_o}^{p} \frac{dp}{p(E-Dp)^2}$$

for the time for the pressure to rise from p_o to p. The constants are defined in ref. 16. The integral may be represented by the terms,

$$I_p - I_{p_o} \equiv \left[\frac{1}{E(E-Dp)} - \frac{1}{E^2 \ln[(E-Dp)/p]} \right]_{p_o}^{p}$$

so that $t = \frac{V_o}{A} \frac{C}{\beta} (I_p - I_{p_o})$. V_o is the free volume. From an experimental p-t curve, 42.4 µsec is required for the pressure to rise from 0.1 kbar to 5 kbar while I_p varies from -0.0263 to +0.0031. A typical value of C/β is 1.714. Therefore, V_o/A is given in terms of these values by

$$\frac{V_o}{A} = \frac{0.0000424}{1.714(0.0031 + 0.02630)}$$

$$= 8.41 \times 10^{-4} \text{ cm.}$$

For a 1 cm cross-section, V_o is roughly 10^{-3} cm^3. A volume of this magnitude may be introduced into a charge by withdrawal of a wire 1 cm long with a diameter of 0.0365 cm. Wire diameters of 0.0226, 0.0320, and 0.0510 cm were chosen for a set of nine shots of which four yielded readable records.

APPENDIX B

Probe Positions and Charge Geometry

I. Strain gage measurements

Item	Distance from Closure End of Tube in.	mm	(referred to hot wire) mm
End of bolt	1.50	38.1	-4.8
Nichrome wire	1.69	42.9	0
Center of strain gage*	2.50	63.5	20.6
First ion probe	3.00	76.2	33.3
Second ion probe	6.00	152.4	109.5
Third ion probe	9.00	228.6	185.7
Fourth ion probe	12.00	304.8	261.9
End of tube	13.50	342.9	300.0

II. Lucite plug shots

			(referred to first probe) mm
End of bolt	1.50	38.1	
Nichrome wire	1.69	42.9	
Maximum distortion**	1.88	47.6	
External probe	2.00	50.8	
First probe (pressure)	2.75	69.9	0.0
Probes 2 (press.& ion)	3.25	82.6	12.7
Probes 3 (press.& ion)	4.00	101.6	31.8
Lucite, front surface	4.75	120.7	50.8
Lucite, back surface	5.00	127.0	57.2

* Gage is 12.7 mm (0.5 in.) square

**Deformation symmetric about this point and covered about 25mm length of tube

APPENDIX B (Cont'd)

Item	Distance from Closure End of Tube in.	mm	(referred to first probe) mm
Group I			
Probes 4 (press.& ion)	5.00+	128.0+	58.2
Probes 5 (press.& ion)	7.00	177.8	108.0
Probes 6 (press.& ion)	9.00	228.6	158.8
Group II			
Probes 4 (press.& ion)	6.00	152.4	82.9
Probes 5 (press.& ion)	7.00	177.8	108.0
Probes 6 (press.& ion)	9.00	228.6	158.8
Group III			
Probes 4 (press.& ion)	5.50	139.7	69.9
Probes 5 (press.& ion)	7.50	190.5	120.7
Probes 6 (press.& ion)	9.50	241.3	171.5

The DDT tubes are seamless, cold-drawn steel, 31.8 mm (1.25 in.) O.D., 12.7 mm (0.5 in.) I.D., 343 mm (13.5 in.) long with the closure occupying 38.1 mm (1.50 in.) of the length and the cast explosive, 305 mm (12.00 in.). The bursting strength of the tubes is, by static tests, above 3.4 kbar (50,000 psi) where the behavior is still elastic (2), and is probably near 5.4 kbar (80,000 psi).

DISTRIBUTION LIST

	No. of Copies
Director, Special Projects Office	
Washington 25, D.C.	
Attn: Code 20	4
Attn: Code 271	1
Attn: Code SP-2710, E. D. Margolin	1
Chief, Bureau of Naval Weapons	
Washington 25, D.C.	
Attn: RUME-32, E. M. Fisher	1
Attn: RUME-33, G. D. Edwards	1
Attn: RMMP-21, O. H. Johnson	1
Attn: RMMP-11, I. Silver	1
Commanding Officer, Naval Propellant Plant	
Indian Head, Maryland	
Attn: Process Development Division	1
Attn: W. C. Cagle	1
U.S. Bureau of Mines	
4800 Forbes Street, Pittsburgh 13, Pennsylvania	
Attn: Dr. C. M. Mason	1
Aerojet-General Corporation, Azusa, California	
Attn: R. F. Chaiken	1
Aerojet-General Corporation, Downey, California	
Attn: Dr. C. L. Zernow	3
Hercules Powder Company	
Allegany Ballistics Laboratory	
P.O. Box 210, Cumberland, Maryland	
Attn: Robert Richardson	1
Attn: Dr. Eyler	1
Attn: Dr. LeBlanc	1
Director, Office of the Secretary of Defense	
Adv. Res. Proj. Agency, Washington 25, D.C.	
Attn: Dr. John F. Kincaid	1
Atlantic Research Corporation	
812 North Fairfax Street, Alexandria, Virginia	
Attn: Dr. Andrej Macek	1
University of Cal. Lawrence Radiation Lab.	
P.O. Box 808, Livermore, California	
Attn: Dr. G. Dorough	1
Los Alamos Scientific Laboratory	
P.O. Box 1663, Los Alamos, New Mexico	
Attn: Dr. L. C. Smith	1
Space Technology Laboratory	
P.O. Box 95001, Los Angeles 45, California	
Attn: Mr. H. A. Taylor	1

DISTRIBUTION LIST (Cont'd)

	No. of Copies
Navy Liaison Office (SP) Air Force Unit Post Office Los Angeles 45, California Attn: M. H. Holt	1
Chief, Bureau of Naval Weapons Washington 25, D.C. Attn: Library, DIS 3	1
Director, Special Projects Office Washington 25, D.C. Attn: Code SP-27	1
Chief, Bureau of Naval Weapons Washington 25, D.C. Attn: RMMP	3
Attn: F-12	1
Aerojet-General Corporation Sacramento, California Attn: Dr. W. Kirchner	4
Lockheed Missiles and Space Company A Division of Lockheed Aircraft Corporation 1122 Jagels Road Sunnyvale, California Attn: Mr. J. Lightfoot	3
Bureau of Naval Weapons Representative (Special Projects Office) Lockheed Missiles and Space Company P.O. Box 504, Sunnyvale, California Attn: SPL-313	2
Bureau of Naval Weapons Resident Representative (Special Projects Office) Aerojet-General Corporation Sacramento, California Attn: SPLA-30	2
Bureau of Naval Weapons Branch Representative Allegany Ballistic Laboratory Cumberland, Maryland Attn: SPH-30	2
Allegany Ballistics Laboratory Hercules Powder Company Cumberland, Maryland Attn: Dr. N. F. LeBlanc	2
Attn: Mr. R. Richardson	2
Aeronutronics A Division of Ford Motor Company Ford Road, Newport Beach, California Attn: Mr. W. Weller	2
Attn: Mr. M. Boyer	1

DISTRIBUTION LIST (Cont'd)

	No. of Copies
Rohm and Haas Company Redstone Arsenal Huntsville, Alabama Attn: Dr. H. Shuey	3
Commander, U.S. Naval Ordnance Test Station China Lake, California Attn: Code 452	2
Attn: Code 5008	1
Armed Services Explosives Safety Board Building T-7, Gravelly Point Washington, D.C. Attn: R. Herman	1
Stanford Research Institute Liquid Propellant Department Propulsion Sciences Division Menlo Park, California Attn: Dr. A. B. Amster	1
Chief, Bureau of Naval Weapons Attn: Library, DIS 3 Washington 25, D. C.	4
Armed Services Technical Information Agency Arlington Hall Arlington, Virginia	10
Office of Naval Research Washington 25, D. C. Code 429	2

CATALOGING INFORMATION FOR LIBRARY USE

BIBLIOGRAPHIC INFORMATION

	DESCRIPTORS	CODES		DESCRIPTORS	CODES
SOURCE	NOL technical report	NOLTR	SECURITY CLASSIFICATION AND CODE COUNT	Unclassified - 24	UØ24
REPORT NUMBER	63-18	63X18	CIRCULATION LIMITATION		
REPORT DATE	February 1963	Ø263	CIRCULATION LIMITATION OR BIBLIOGRAPHIC		
			BIBLIOGRAPHIC (SUPPL., VOL., ETC.)		

SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Pentolite	PENI	Curves	CURV		
Deflagration	DEFA	Transition	TRNI		
Detonation	DETO	High explosives	HIGX		
Burning	BURN	Propellants	FUEL		
Volume	VOLU	Ignition	IGNI		
Low speed	LOWS	Steady state	STBI		
Velocity	VELC	Subsonic	SUBS		
Explosives	EXPL	Ionized	IONI		
Cast	CAST	Front	FRON		
Pressure	PRES	Sensitivity	SENV		
Time	TIME	Explosions	EXPS		
Lucite	LUCI	Filter	FILT		

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-18)
TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE (U), by Donna Price and others. 12 Feb. 1963. 33p. illus., diagr., tables. Project FR-59.
UNCLASSIFIED

Free volume (ca. $10^{-3}cm^3$) introduced near the ignition wire did not affect the pressure-time curve in confined explosive burning. Rupture of the casing for shots which detonated occurs 100 msec or more after a pressure of 1 kbar is attained. Plastic deformation requires 45 msec. Initiating pressures are thus reached near the igniter for DINA and Pentolite. The negligible effect of a Lucite filter on the propagation of the subsonic ionization front show that this front is pressure initiated and propagated; it is not a flame front.

1. Explosives - Deflagration
2. Explosives - Detonation
3. Propellants - Deflagration
4. Propellants - Detonation
5. Pentolites
I. Title
II. Price, Donna
III. Project

Abstract card is unclassified.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-18)
TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE (U), by Donna Price and others. 12 Feb. 1963. 33p. illus., diagr., tables. Project FR-59.
UNCLASSIFIED

Free volume (ca. $10^{-3}cm^3$) introduced near the ignition wire did not affect the pressure-time curve in confined explosive burning. Rupture of the casing for shots which detonated occurs 100 msec or more after a pressure of 1 kbar is attained. Plastic deformation requires 45 msec. Initiating pressures are thus reached near the igniter for DINA and Pentolite. The negligible effect of a Lucite filter on the propagation of the subsonic ionization front show that this front is pressure initiated and propagated; it is not a flame front.

1. Explosives - Deflagration
2. Explosives - Detonation
3. Propellants - Deflagration
4. Propellants - Detonation
5. Pentolites
I. Title
II. Price, Donna
III. Project

Abstract card is unclassified.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-18)
TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE (U), by Donna Price and others. 12 Feb. 1963. 33p. illus., diagr., tables. Project FR-59.
UNCLASSIFIED

Free volume (ca. $10^{-3}cm^3$) introduced near the ignition wire did not affect the pressure-time curve in confined explosive burning. Rupture of the casing for shots which detonated occurs 100 msec or more after a pressure of 1 kbar is attained. Plastic deformation requires 45 msec. Initiating pressures are thus reached near the igniter for DINA and Pentolite. The negligible effect of a Lucite filter on the propagation of the subsonic ionization front show that this front is pressure initiated and propagated; it is not a flame front.

1. Explosives - Deflagration
2. Explosives - Detonation
3. Propellants - Deflagration
4. Propellants - Detonation
5. Pentolites
I. Title
II. Price, Donna
III. Project

Abstract card is unclassified.

Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 63-18)
TRANSITION FROM SLOW BURNING TO DETONATION: FURTHER STUDIES OF THE FREE VOLUME AND THE LOW VELOCITY REGIME IN CAST PENTOLITE (U), by Donna Price and others. 12 Feb. 1963. 33p. illus., diagr., tables. Project FR-59.
UNCLASSIFIED

Free volume (ca. $10^{-3}cm^3$) introduced near the ignition wire did not affect the pressure-time curve in confined explosive burning. Rupture of the casing for shots which detonated occurs 100 msec or more after a pressure of 1 kbar is attained. Plastic deformation requires 45 msec. Initiating pressures are thus reached near the igniter for DINA and Pentolite. The negligible effect of a Lucite filter on the propagation of the subsonic ionization front show that this front is pressure initiated and propagated; it is not a flame front.

1. Explosives - Deflagration
2. Explosives - Detonation
3. Propellants - Deflagration
4. Propellants - Detonation
5. Pentolites
I. Title
II. Price, Donna
III. Project

Abstract card is unclassified.